High Temperature Materials Laboratory

Residual Stress Mapping of High Strength Steel Weldments to Improve Fatigue Life

Background

Attempts to improve fuel economy in both on-highway and off-highway vehicles are increasing due to oil shortages and environmental factors. Reducing the weight of vehicles can contribute to improved fuel economy. However, designing and producing lighter weight structures for these vehicles with high strength materials is limited by the low fatigue strength of welded joints.

High tensile residual stresses are usually formed in high-strength steel welds. High tensile residual stresses accelerate fatigue crack propagation and reduce weld fatigue life, which makes developing fatigue-resistant welds a major technical barrier.

A systematic approach was developed by Caterpillar to improve the fatigue life of a welded joint by 10 times and to reduce energy use by 25 percent. The approach involved developing special welding wires and evaluating the weld process with the goal of introducing compressive residual stress at the weld toe of high strength steel welds. The residual stress facilities at the High Temperature Materials Laboratory (HTML) were used by Caterpillar to characterize the residual stresses at critical locations in the vicinity of their experimental welds.

Figure 1. *High strength welded steel sample mounted and ready for stress mapping at the new neutron residual stress mapping facility.*

Technology

Diffraction is used to probe the crystal structure of materials. Specifically, the spacing between planes of atoms can be accurately measured. Applied or residual forces pull or squeeze

Benefits

- Significant reduction of detrimental tensile residual stresses improves fatigue life.
- Increased use of high strength steel enables reduced vehicle weight.

the crystal structure, changing the spacing of these planes. This change can be measured and converted into a residual stress. Diffraction can be accomplished with X-rays and neutrons, which provide information from the surface and bulk of a material, respectively. Measurement at many locations within the specimen and its surface leads to maps of residual stresses. These stress maps are used for life prediction and model validation.

Neutron strain mapping was performed using the new Neutron Residual Stress Mapping Facility operated by the HTML at the High Flux Isotope Reactor. An advanced monochromator delivers a high flux of neutrons to the sample. Computer controlled stress mappings along lines two and three (see Figure 2) were collected for three different weld metals.

Residual stresses along line 1 of Figure 2 were mapped starting from the weld toe out 5 mm

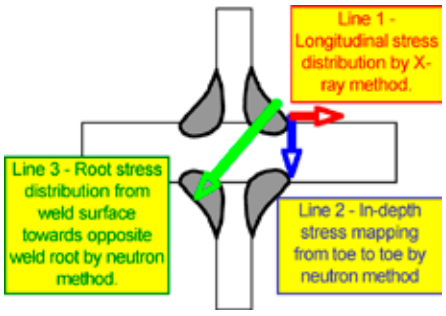

Figure 2.

using HTML's large specimen X-ray diffraction facility with computer controlled specimen positioning. The X-ray system consists of a portable X-ray stress analyzer mounted overhead to a gantry which forms the frame for a 15 × 8.2 × 9.2 ft (L × W × H) shielded enclosure. This setup can accommodate small and large samples up to 250 lb.

Status

The measured residual stresses for the three types of welded joints investigated are more compressive than in the conventional weld. The stresses are consistent with those from the simulation, that is, tensile residual stress at weld toe with conventional welding wire and compressive residual stress at weld toe with special welding wires.

The predicted fatigue life using a two-stage crack growth model considering the effect of compressive residual stress with special welding wire welds are in reasonable agreement with the high end of fatigue test results, which show more than 10 times the fatigue life improvement in high strength steel welded joints.

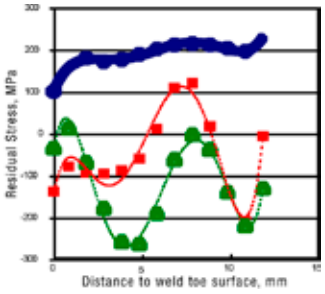

Figure 3. *Measured residual stress maps along line 2 in the direction perpendicular to the weld line for the conventional weld (blue) and special welding wires (red and green).*

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